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Shallow-Focus Seismicity and Tectonic Structure of the Sea of Japan

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Abstract—The analysis of the available seismological data on the Sea of Japan region made it possible to prepare the first complete unified catalog of earthquakes with $M \geq 3.0$ and $h \leq 60$ km for the period of 1975–2010. Four maps of epicenters for different depth intervals (0–10, 11–20, 21–30, and 31–60 km) and three sublatitudinal sections 1° wide are constructed. The analysis includes the structural features and the probable tectonic nature of the seismoactive zone along the underwater margin or borderland of the Japan–Sakhalin island arc: the regional or, more exactly, megaduplex of compression faults determined by the crust sliding in the back part of the frontal deep-seated thrust. The crustal seismicity in the southeastern margin of the Korean Peninsula (the Sino-Korean Shield) is likely related to the Tsushima and Ullyndo faults. It is assumed that it may provoke block, potentially thsunamigenic landslides in the southern and eastern cirques of the Ullyndo Basin incised into the underwater delta of the Huanghe River.

Keywords: shallow-focus (crustal) seismicity, crustal tectonics, borderland, back reversed fault, landslide, Sea of Japan, Japan–Sakhalin arc

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INTRODUCTION

The Japan–Sakhalin island arc is located in the Pacific seismic belt, which experiences frequent earthquakes (>80% of all the seismic events) with many of them being of catastrophic intensity. The arc separates the Sea of Japan basin, which is the main object of this study, from the Pacific Ocean (Fig. 1). The Pacific margin of the Honshu (Tohoku or Northeastern Japan) arc, which represents an element of the Japan–Sakhalin island arc, is characterized by the maximal seismic activity on the Earth. This is explained by the confinement of most of the seismic events in this area to the Benioff (or, more exactly, the Wadati–Zavaritskii–Benioff) seismofocal zone, which subsides under the arc. The existence of this zone is determined by the subduction at the boundary between the Amur and Pacific lithospheric plates [47]. Precisely this area is marked by the strongest earthquakes, which are accompanied by tsunamis. These catastrophic natural events result in colossal damage and many victims. This is best exemplified by the megaearthquake (M_w = 9.0) that happened east of northern Honshu Island on March 11, 2011. It generated giant tasunamis over 10–20 m high, which resulted, in turn, in the unprecedented technogenic catastrophe at the coastal Fukushima-1 nuclear power plant [45].

The level of the shallow-focus seismicity in the Sea of Japan is slightly lower, although sufficiently high particularly near the eastern coast, which is subjected to regular strong earthquakes. Only during the last half-century has this area experienced sufficiently well known damaging events such as the Niigata in 1964 ($M = 7.5$), Moneron in 1971 ($M7.5$), Sea of Japan in 1983 ($M = 7.7$), Okushiri in 1993 ($M = 7.8$), and Nevel'sk in 2007 ($M = 6.2$) earthquakes. Such a situation is explained by the position of their centers along the boundary between the Amur and Sea of Japan lithospheric plates [3, 47], which extends from Niigata (Honshu Island) to northern Sakhalin (Fig. 1, inset).

The study of the offshore seismicity is characterized by its specific features in comparison with similar onshore investigations. The catalogs of earthquakes available for marine domains are less complete and accurate; the determination of their hypocenters is generally lower as compared with the onshore areas. The sea bottom is difficult to access for seismic investigations. The seismicity level in the central parts of the marginal seas is usually lower than in their peripheral areas. Moreover, some areas may significantly differ in the seismicity level from both the particular and other seas.

The Sea of Japan is a basin well investigated with geological–geophysical methods, including dredging and drilling of the Cenozoic sedimentary cover and Mesozoic–Paleozoic to, locally, Precambrian basement [1, 5, 16, 23, 27, 28, 35–38]. Therefore, it has served for a long time as an area for testing different hypotheses and ideas, which usually reflect two concepts: fixistic (the geosynclinal concept, basification of the old continental crust, and riftogenesis) and mobilistic (the tectonics of the lithospheric plates, the mantle diapirism and riftogenesis [13], and the left-lateral shear between Eurasia and the Pacific Ocean [17]).

In several points, they are similar to each other. These features in common are the mantle diapir, the suboceanic crust 12–15 km thick beneath the Central Japan, Honshu, and Ullyndo bathyal basins with the continental Yamato block at their junction; the rifting; and the Cenozoic history. The first concept implies the epioceanic initiation of the basin as an element of the Pacific Ocean and the formation of its structures in situ without significant horizontal displacements of the crust in the Mesozoic–Cenozoic times. According to the second concept, the dominant processes were the Cenozoic spreading (rifting) and the horizontal motion of the Japanese arc from Eurasia in the eastern direction. The nature of the borderlands, the complex structure of the Korean Peninsula's (the Korean Shield) margins, and the Japan–Sakhalin arc [1, 23, 28, 38] remain debatable. Beneath these domains, the crust's thickness increases by 2–3 times (to 30–40 km and more) with the simultaneous changing of its type: the suboceanic crust is replaced by the continental one.

The purpose of this work is the colligation of the most complete data on the recent shallow-focus ($h <$ 60 km) seismicity of the Sea of Japan, the preparation of an original catalog of earthquakes, and the preliminary revealing of the relations between the seismicity of this basin and its tectonics. The gathering of materials on the seismicity is culminated in the compilation of the complete catalog of earthquakes with $M \geq 3$ based on the analysis of the Russian and foreign seismological summaries for the period of 1975–2010, when national networks of seismological observations became able to provide more reliable information on the weak earthquakes in the Sea of Japan.

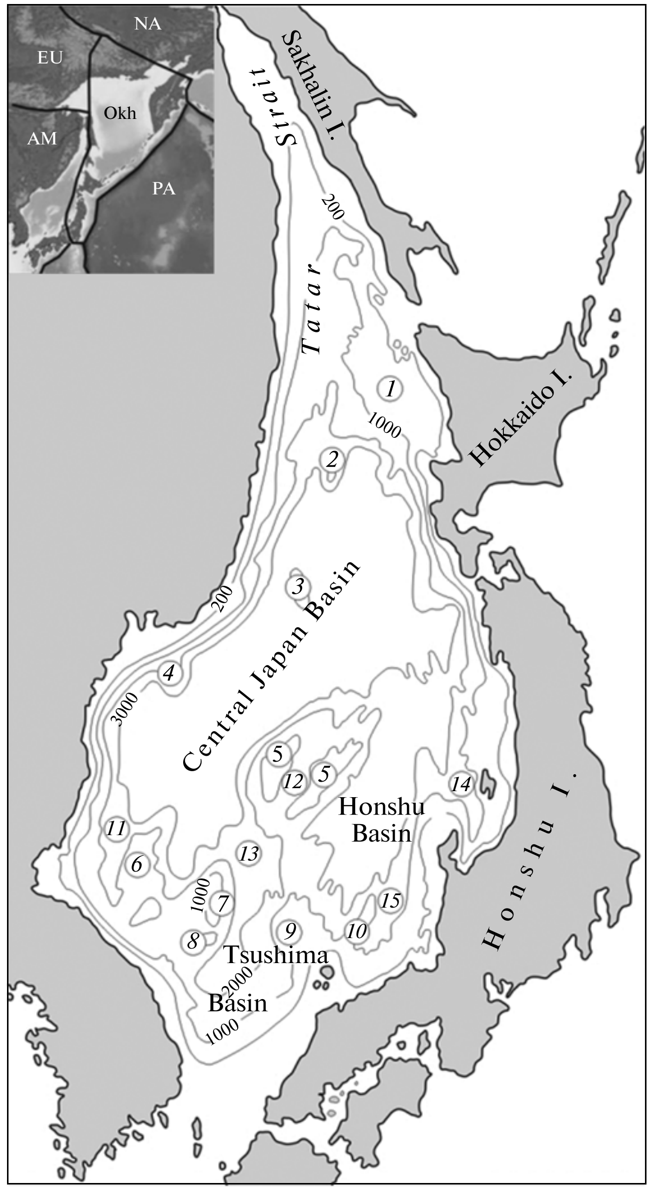


Fig. 1. Bathymetric chart of the Sea of Japan with elements of the morphography.

The underwater rises: (*1*) South Tatar, (*2*) Vityaz, (*3*) Bogorov, (*4*) Pervenets, (*5*) Yamato, (*6*) East Korean, (*7*) Krischtofovich, (*8*) Ullyndo, (*9*) Przheval'skii, (*10*) Oki. The underwater valleys: (*11*) Genzan, (*12*) Kita–Yamato, (*13*) West Yamato, (*14*) Toyama, (*15*) Oki. The inset presents the schematic position of the lithospheric plates [47]: the (NA) North American, (EU) Eurasian, (AM) Amur, (PA) Pacific, and (Okh) Okhotsk.

SHALLOW-FOCUS SEISMICITY OF THE SEA OF JAPAN DOCUMENTED IN THE ORIGINAL CATALOG OF EARTHQUAKES FOR THE PERIOD OF 1975–2010

The seismicity in the Sea of Japan is registered by several national seismological surveys (the Russia, the Japanese, and the Democratic People's Republic of Korea) and is also summarized in the bulletins of the NEIC/USGS and the International Seismological Center (ISC) world agencies [6–12, 14, 44, 24, 25, 39–41]. Precisely these data sources were used in the present work.

The bulk of the information on the seismicity of the Sea of Japan for the period of 1975–2010 was derived from the Catalog of the Japanese Meteorological Agency [40]. Approximately 92.3% of all the events mentioned in the composite catalog are taken from this catalog. Beginning from 1998, the accuracy in assessing positions of the hypocenters of the shallow-focus earthquakes averages 0.7, 1.5, and 1.5 km in latitude, longitude, and depth, respectively. For the period under consideration, several strong and catastrophic earthquakes were registered in the Sea of Japan, which were accompanied by many aftershocks. The information on the aftershock successions accompanying these earthquakes constituted a significant share of the events cited in the composite catalog presented in this work.

The second (in significance) catalog of earthquakes registered in southern Sakhalin by the local network of digital seismic stations provides information on 4.7% of the seismic events [14]. This catalog includes the most complete and accurate estimates of the parameters of the aftershocks from the Nevel'sk August 2, 2007, earthquake ($M = 6.2$), which are mentioned in the composite catalog, while doubling, less accurate estimates from other catalogs are omitted. The third (in significance) place (2.3% of the events cited in the composite catalog) belongs to the regional catalog available for the entire Sakhalin [24]. The data on the seismicity of the western shelf of middle and central Sakhalin in the period beginning from the end of September of 2005 were taken from the Operative catalog of the Sakhalin branch (the Geophysical Survey of the Russian Academy of Sciences) [22]. This and other catalogs provided an insignificant share of the information (approximately 0.7%).

The data from the USGS/NEIC world catalog [19], the Russian summaries on the Primor'e and Amur regions [7–11, 25], and the Korean sources [6, 12, 41] were used for characterizing the seismic events in the western part of the Sea of Japan.

The data selection in the composite catalog of earthquakes is time-unified. The origination moments of the seismic events are reduced to the Japan standard time (JST). These works resulted in the compilation of the catalog of recent ($M \geq 3.0$, $h \leq 60$ km) earthquakes in the Sea of Japan that happened in the period of 1975–2010, which contains information on 9513 seismic events. Figures 2 and 3 present maps of the earthquake epicenters from the composite catalog for different depth intervals, and Figure 4 illustrates the vertical sublatitudinal sections of the seismoactive domains for the northern, central, and southern parts of the Sea of Japan. The axial lines of these sections are located at 37°, 41°, and 45° N. The width of the bands covered by these sections is 1°.

The maps of the earthquake epicenters demonstrate that the surface seismicity in the Sea of Japan is mainly confined to the underwater margin of the Japan–Sakhalin island arc in the area located approximately between 34 to 52° N. On the western coast of the sea in the Korean Peninsula area, the seismicity level notably decreases to fall almost to zero values in the extended area along the coast of the Democratic People's Republic of Korea and the Primor'e and Khabarovsk regions of the Russian Federation.

The only exception is the November 13, 1990, event with ($M = 6.3$) [25]. It is anomalous with respect to both the location and intensity. The maximal earthquake magnitude in the residence areas located in the vicinity of its center was likely as high as 5–6 on the MSK scale. No such strong earthquakes were documented in this area during the last century. The center of the earthquake is confined to the boundary that separates the Late Mesozoic (Cretaceous) Sikhote Alin orogen from the younger Late Cenozoic (Neogene) Tatar synclinorium [30].

For the period under consideration, the central part of the Sea of Japan was aseismic at the level of magnitudes $M \geq 3.0$. This is partly explained by the difficult access to the sea bottom for seismological investigation and the specifics of the organization of the seismic observational network of the Japanese Meteorological Agency. This network is aimed at the registration of seismic events on the Japanese Islands and in their vicinity. Therefore, the representativeness concerning the registration of weak earthquakes decreases away from the seashore [31, 34].

While the distribution of the earthquake epicenters in the Sea of Japan was quite expectable, the near-vertical distribution of their hypocenters along the sublatitudinal sections appeared to be unexpected in light of the present-day concepts of the inclined subduction zone in the Japan–Sakhalin back arc [27, 46].

A similar near-vertical distribution of the hypocenters of the weak earthquakes ($M = 2–3$) in the Japan region is noted in [2]. These so-called seismic "nails" 5–10 km in diameter and 10–50 km deep represent, however, local structures independent of the shallow-focus seismicity zone in question along the underwater margin of the Japan–Sakhalin island arc. Moreover, Vadkovskii [2] notes the lack of direct correlation between such "nails" and strong ($M > 5.0$) earthquakes.

PROBABLE RELATIONS BETWEEN THE SHALLOW-FOCUS SEISMICITY ZONES AND THE CRUSTAL TECTONICS IN THE SEA OF JAPAN

Judging from Figs. 2–4, most of the earthquakes are observed beneath the underwater margin of the Japan–Sakhalin arc in the area corresponding to the boundary between the Amur and Okhotsk lithospheric plates (Fig. 1, inset). The recently discovered zone of convergence and the late Pliocene–Quaternary subduction of the Sea of Japan's bottom (plate) in the eastern direction in response to the Baikal rift's opening (see the reviews in [27] and [46]) are thought to be related to the Hokkaido and Honshu margins. The subduction rate is as high as 2 cm/year, and the depth the plate's subsidence and the related earthquakes amounts to 50 km. This idea takes into consideration the dominant eastward displacements of the GPS recording stations between Lake Baikal and the Sea of Japan, the insignificant (20–30 km) depth of the shallow-focus earthquake centers beneath the islands, and their likely stable position for the last 2 myr.

In the context of this work, it should be noted that the Northeast Japanese, or Tohoku ("to" in Japan means north and "hoku," east), arc occupies, together

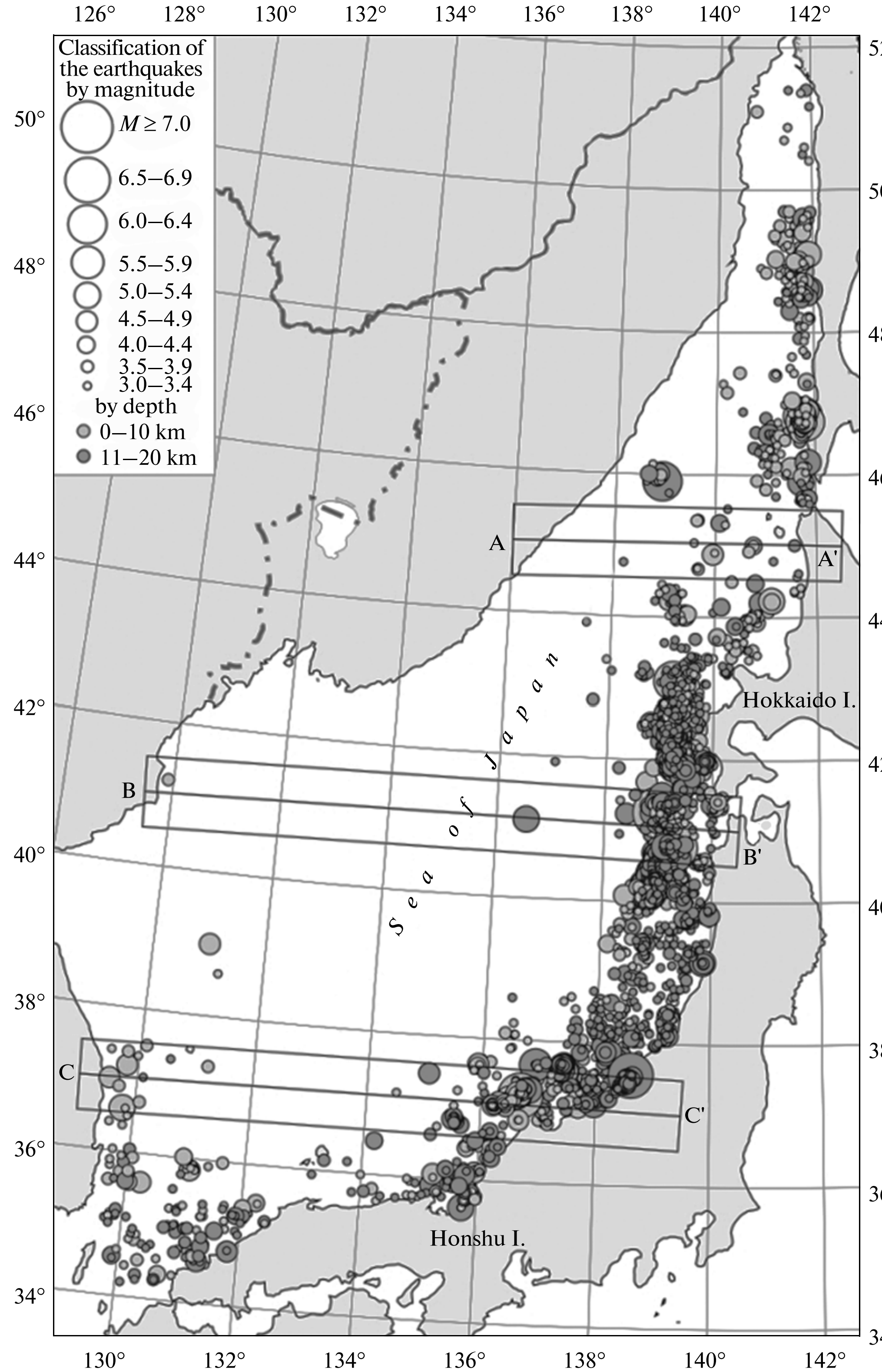


Fig. 2. Distribution of the epicenters of the earthquakes with $M \geq 3$ at depths of 0–10 and 11–20 km in the Sea of Japan for the period of 1975–2005 after the original catalog.
(A–A', B–B', C–C') axial lines of the vertical latitudinal sections of the seismoactive bands ±0.5° wide relative to the axial lines.

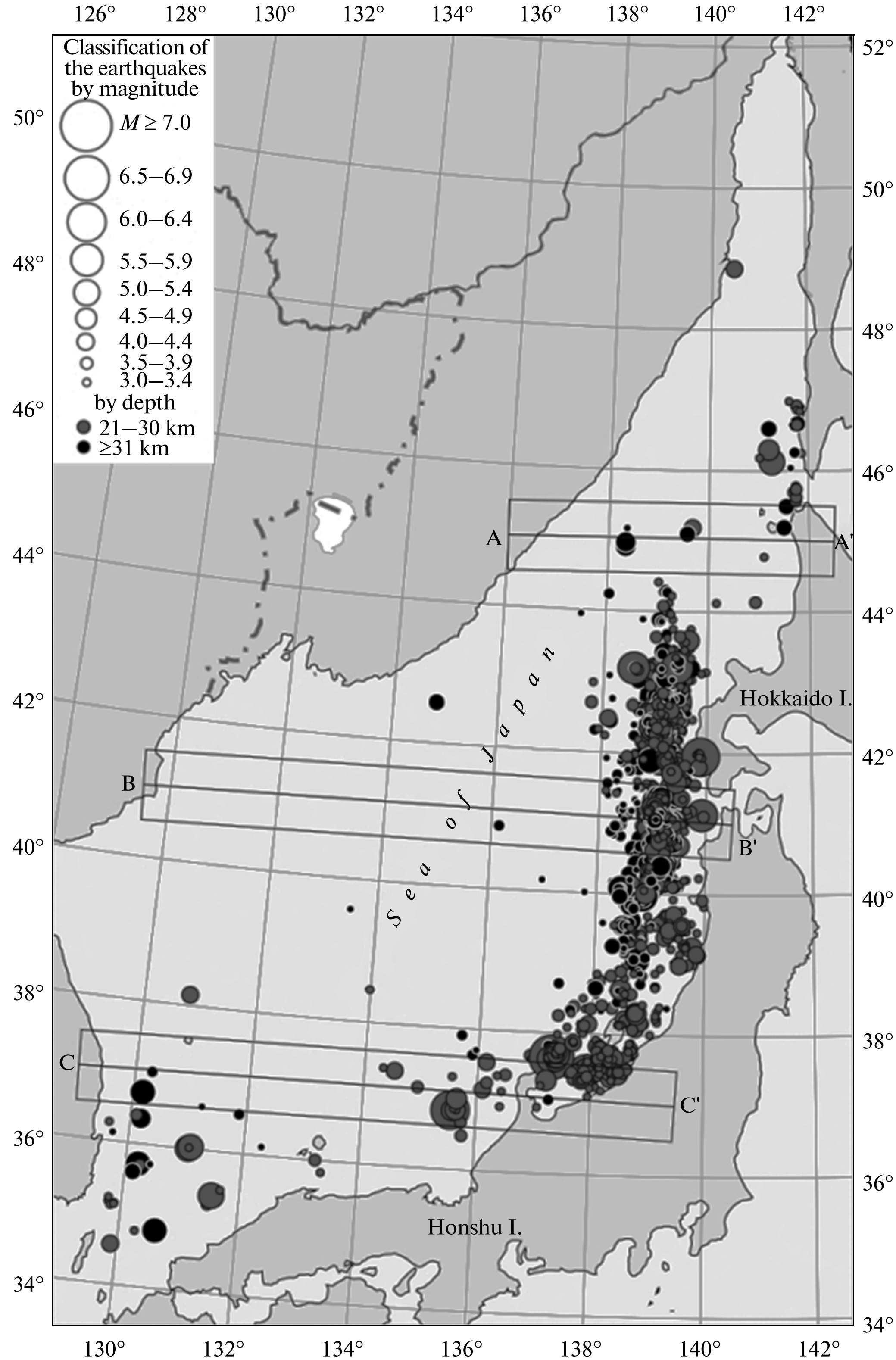


Fig. 3. Distribution of the epicenters of the earthquakes with $M \geq 3$ at depths of 21–30 and 31–60 km in the Sea of Japan for the period of 1975–2005 after the original catalog.
For the explanation of the figure, see Fig. 2.

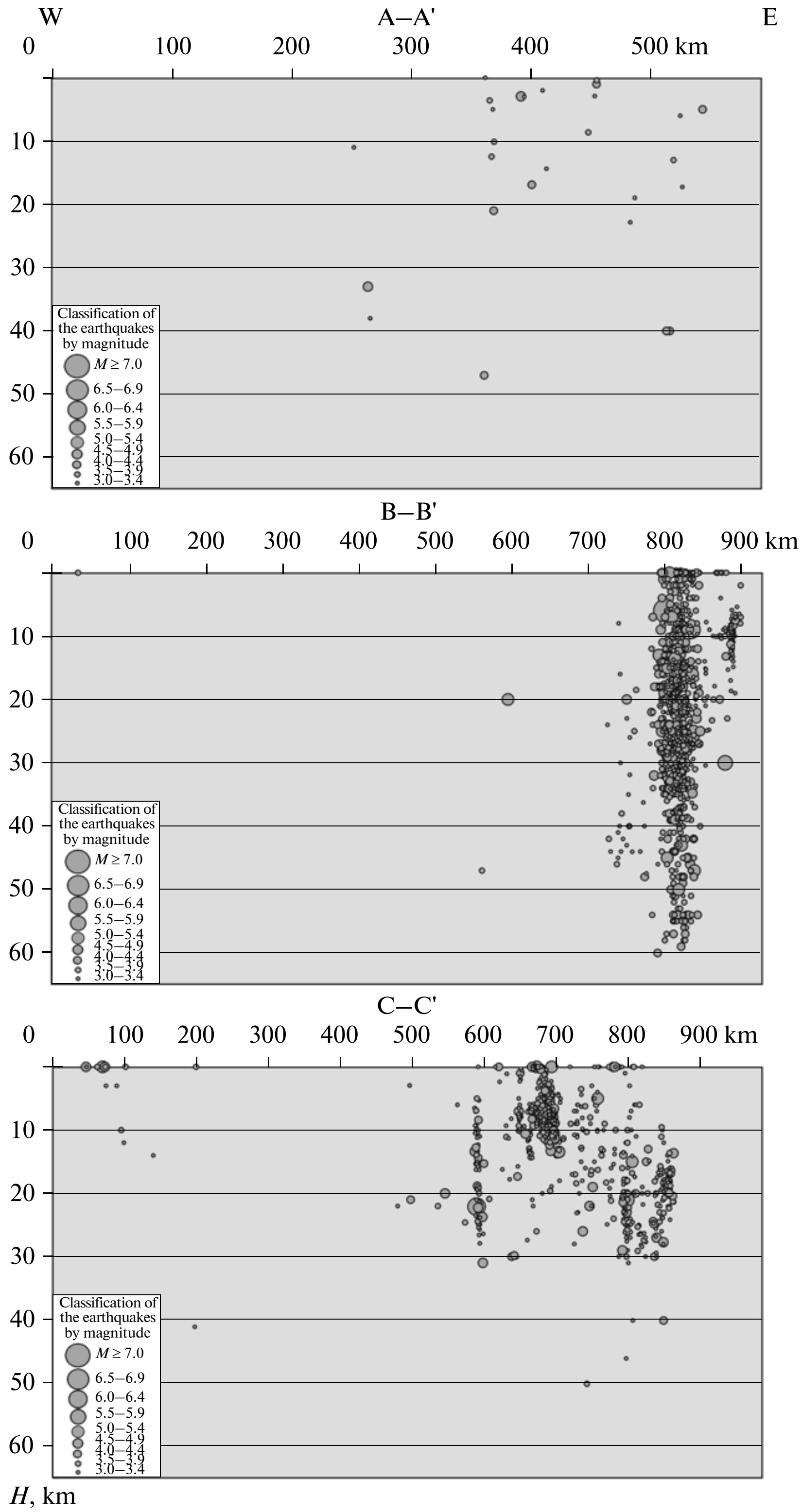


Fig. 4. Vertical latitudinal sections through seismoactive domains along lines A–A', B–B', and C–C' within bands ±0.5 wide relative to the axial lines.

The coordinates of the line ends: A (45.0° N; 135.0 E), A' (45.0° N; 142.5 E), B (41.0° N; 129.0 E), B' (41.0° N; 140.5 E), C (37.0° N; 129.0 E), C' (41.0° N; 139.5 E).

with the opposite Benioff and Tarakanov seismofocal zones (Fig. 5A), the reentering structural angle with the apex located near Vladivostok. It is formed by the frontal deep-seated thrusts of the Benioff zones of the Izu–Mariana and Kuril–Kamchatka arc–trench systems, which is confirmed by the seismic isobath maps in [32].

Another aspect concerns the results of the interpretation of the CMP data and the sediment balance in the accretionary wedge of the Japanese Trench (Fig. 5B; [17]), according to which the Tohoku arc has been thrust over the Pacific Ocean's bottom along the Benioff zone approximately for 90 km during the last 0.5–1.0 myr. Its frontal part forms the Oyashio crustal overthrust 10–20 km thick, which is responsible for the March 11, 2011 Tohoku earthquake and tsunami [45].

Inasmuch as the Sea of Japan is lacking an arc-parallel rift (spreading) of similar width [1, 16, 23, 28, 38], the crust beneath the latter is allochthonous, i.e., detached from its base (an areal tectonic overthrust). As follows from Figs. 2–4, a significant part of the sea is almost aseismic at the $M \geq 3$ level. The seismic activity for weak earthquakes ($M \sim 1–2$) may be estimated using bottom seismographs; unfortunately, no such information is available. The differences in the bottom's topography and the acoustic basement's surface exceeding 2–3 km [1, 5, 28] indicate the probable existence of a notable weak seismicity background.

The main zone of shallow-focus seismicity 100–200 km wide and approximately 2000 km long extends along the margin of the Japan–Sakhalin island arc. The second, smaller zone corresponds to the northern exit from the Tsushima Strait and the southeastern underwater margin of the Korean Peninsula (the Sino-Korean Shield). The deep-seated faults probably related to the Benioff zone of the Izu–Mariana arc [32] and marked by a synonymous megadike 220 × 5 km in size with the corresponding linear positive Bouget gravity anomaly may be assumed in the Tsushima Strait area (the Mesozoic–Cenozoic Nakton marginal trough) (Fig. 6; [20, 36]).

Along the Japanese–Sakhalin borderland, the seismoactive zone is characterized by the near-vertical dip's widening and deepening from its flanks toward the central part (approximately between 45 and 38° N) from 30–50 to 60–70 km (Fig. 4). With respect to the tectonics, the latter may be related to the young breakup, longitudinal shear, or subduction zone [46]. It is conceivable that the near-vertical dip of the hypocenter zone reflects the regional bent (root zone of the frontal deep-seated thrust) in the crustal layers and upper mantle at the transition from their subhorizontal position beneath the Sea of Japan to the inclined one under the borderland.

Figure 5 illustrates the tectonic features of the underwater margin of the Japan–Sakhalin arc. It represents a model of the divergent orogen bordered by opposite marginal compression faults [33]. This model was recently proposed for the Kamyshovyi anticlinorium of Sakhalin [19, 21] and the Japan–Sakhalin arc in this work. The model's selection is justified by the materials on the Moneron 1971; Uglegorsk 2000; Noto 2007; and, likely, Nevel'sk 2007 earthquakes [3, 4, 15, 26, 42] indicating the eastward dip of the main seismic fractures under the island arc. It should, however, be specified that the latter represents a cylindrical reversed fracture in the duplex of the West Sakhalin regional fault [21].

As follows from Fig. 5, the seismoactive zone of the regional back reversed fault (megaduplex) and the divergent structure of the Japan–Sakhalin arc were formed in response to the gravitational crust sliding in the back part of the frontal deep-seated thrust. In Sakhalin and Japan, the latter is termed as the Central Sakhalin and Oyashio overthrusts, respectively (Figs. 5A, 5B; [17, 45]). Taking into consideration the suggestions by G.D. Azhgirei, L.P. Zonenshain, and some other researchers concerning the assessment of the changes in the crust area when determining the fault types in their transverse sections, it becomes clear that the near-vertical back reversed fault acquires with depth an incline toward the uplifted active island-arc block in the manner shown in Fig. 5B [21]. Owing likely to the substantial difference in the crustal sliding scales in the back part of the deep-seated thrust in the Benioff zone and the Central Sakhalin updip–thrust, the back reversed faults are arranged in an echelon manner: the former extends further westward as com-

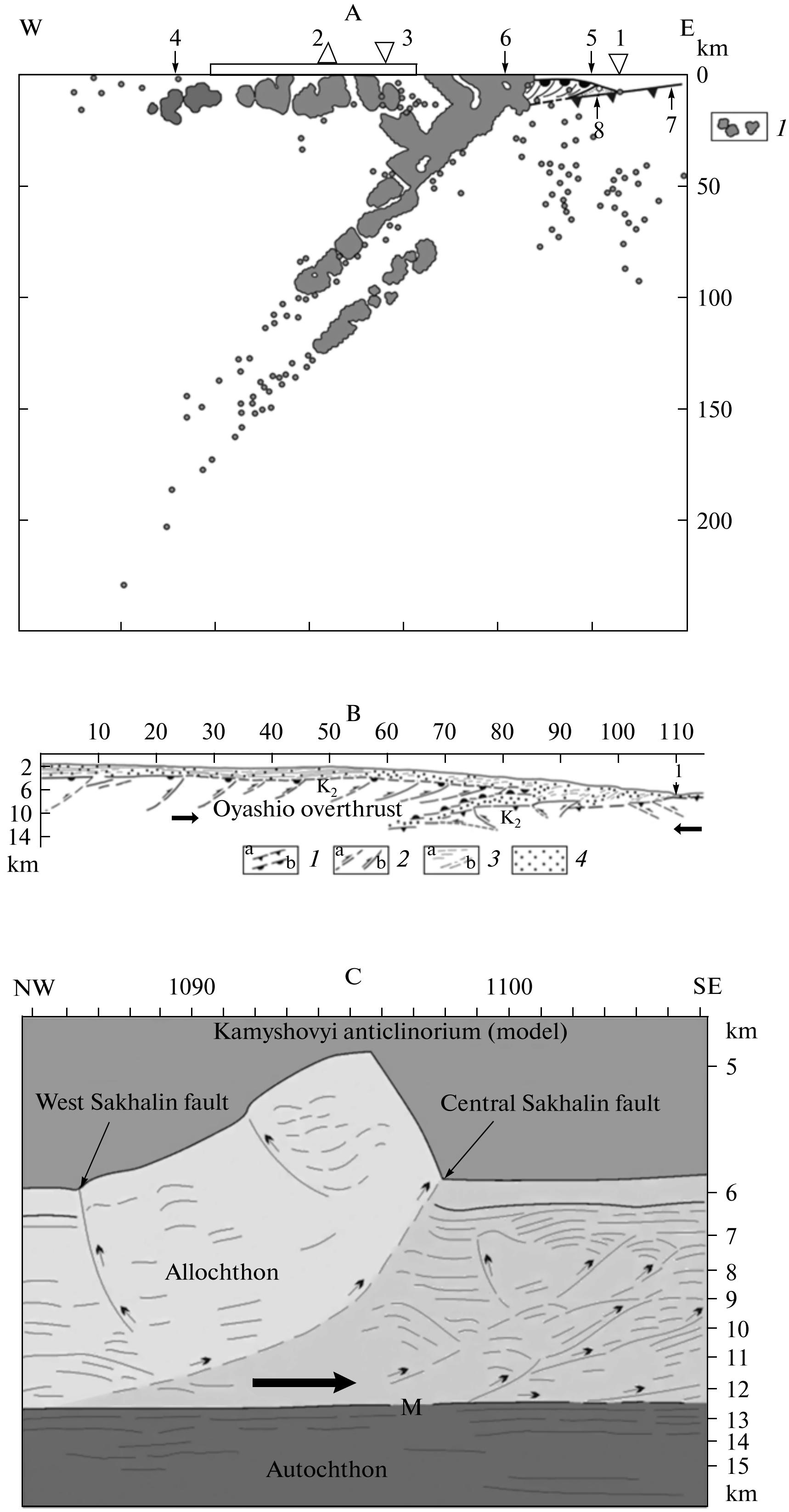
Fig. 5. (A) juxtaposed latitudinal section of the opposite seismofocal zones and the CMP JNOC 2 profile (B) in the northern Honshu arc (Tohoku) near 39° N [17, 34].

(1) thalweg of the Japanese Trench; (2, 3) the volcanic and aseismic fronts, respectively; (4) the base of the Sea of Japan margin; (5, 6) the front and root of the Oyashio overthrust, respectively, are also indicated by the black semicircles and the inclined lines (faults); (7) the surface of the mobile autochthon (layer of the Northwest plate); (8) the accretionary wedge. The Italic number: (*1*) clouds of earthquake hypocenters.

(B) deep section CMP JNOC 2.

(*1*) surface of the Late Cretaceous acoustic basement in allochthon (a) and autochthon (b); (*2*) compression faults: assumed (a) and proven (b); (*3*) reflectors related to turbidite lenses (a) and thrusts in the accretionary wedge (b); (4) the Cenozoic sedimentary cover and accretionary wedge (cloud of dots); the number 1 in the section designates the accretion front at the base of the Pacific slope of the island arc.

(C) fragment of the deep CMP1 section with the thrust monoclonal ridge from the divergent detachment zone at the Northwest Pacific bottom: model of the Kamyshevyi anticlinorium (monocline) of the Sakhalin and Japan arc [19].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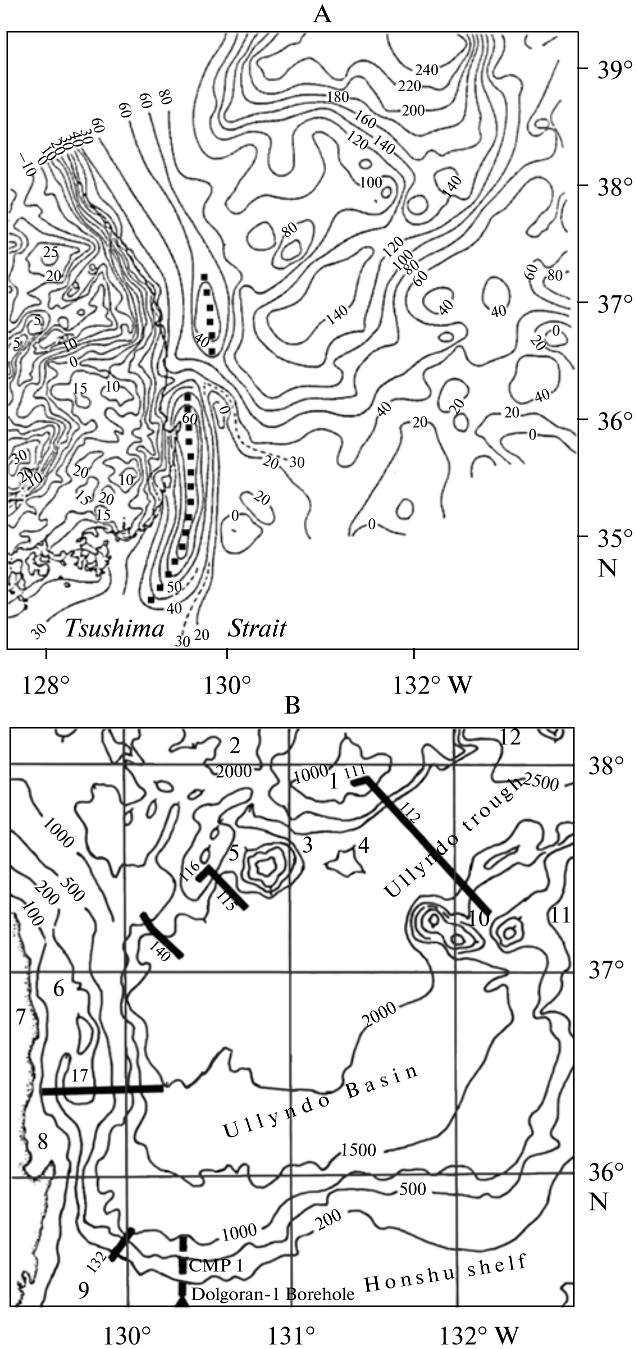

Fig. 6. (A) Bouguet gravity map of the Korean Peninsula and its southeastern margin [36] with isoanomalies ranging from 5 (the land and shelf) to 20 mGal (the continental slope); the line of black squares designates the Tsushima megadike and the synonymous deep-seated fault [18]; (B) bathymetric chart of the Ullyndo (Tsushima) Basin and trough with continuous seismic profiling (Figs. 7a–7c) and the CMP records (the dotted line across the Dolgoran-1 Borehole designated by the black triangle [18, 37]; Fig. 8c): (1) Ullyndo Plateau, (2) East Korean trough, (3) underwater Vonsan valley [44], (4) Mount Glebov, (5) Ullyndo Island, (6) Hupo sedimentary basin, (7) Sobek massif, (8) Pohang sedimentary basin, (9) Nakton marginal trough, (10) Chukto Volcano and Islands, (11) Oki Ridge (Przheval'skii [1]), (12) West Yamato "bay" of the Central Basin of the Sea of Japan [1].

pared the latter to continue in the northern direction up to 46° N (Fig. 2). In this connection, the notable November 13, 1990, event with $M = 6.3$ in Fig. 2 registered near the intersection of 46° N and 139° E may be considered as indicating the continuation of the reversed fault in the back part of the deep-seated fault in the Benioff zone. In such an interpretation, this event does not look anomalous with respect to its location and intensity.

In the southern Sea of Japan, the seismoactive zone in the Japan–Sakhalin back arc comprises the eastern and southern areas of the small Ullyndo bathyal basin and partly the eastern Tsushima (Korean) Strait. Most shallow-focus earthquakes in this area occur in the vicinity of the Tsushima megadike (Fig. 6a, 6b, and 8a) likely marking the synonymous deep-seated fault [20] and in the NE-extending band on the Korean borderland 50–70 km away from the Ullyndo Basin and trough. The remaining part of the borderland with the adjacent continental margin is aseismic.

Steep, locally stepwise (normal faults and flexures) slopes separate the borderland or, more exactly, the underwater continuation of the Sobek massif from the Ullyndo Basin and trough. These features provide grounds for tracing the large Ullyndo fault in this area [28]. Its steep hanging wall with the Ullyndo Plateau (Krischtofovich Rise [1]) that crowns the Sobek massif is composed of Archean rocks covered by thin Meso-zoic–Cenozoic sediments [23, 28]. The latitudinal asymmetry of the bottom topography indicates its monoclonal structure, which allows the Ullyndo fault in the frontal part of the Korean borderland to be considered as representing a cylindrical updip–thrust with the northwestern dip of its plane at angles of 10–20° (Fig. 5A). This explains the occurrence of rare upper crustal earthquakes 50–70 km west of the latter and the aseismicity of its bottom projection zone (Figs. 2, 3).

Noteworthy is the crustal seismicity (monitoring) in the northern Tsushima (Korean) Strait's exit and the adjacent shelf of Honshu Island, where two large (the southern and eastern, respectively) landslide cirques of the Ullyndo Basin exhibit regressive erosion and the formation of block potentially tsunamigenic landslides (Fig. 8b; [18]). They slide from the upper step of the continental slope along the regionally inclined surfaces within the Neogene–Quaternary Huanghe underwater delta toward the Ullyndo Basin (Fig. 8a). The cirques that were formed in the middle–late Pleistocene owing to large landslides (mudflows) of poorly consolidated sandy–clayey sediments (according to the Dolgoran-1 parametric well drilling results [37]) mark the front of the underwater delta. On the basin's bottom, they form two–three landslide units (stratiform landslides) with semitransparent rugged seismic facies in the continuous seismic profiling records (Fig. 7c; [18]). At the same time, in [29], its authors report in the section "Asian continent coast"

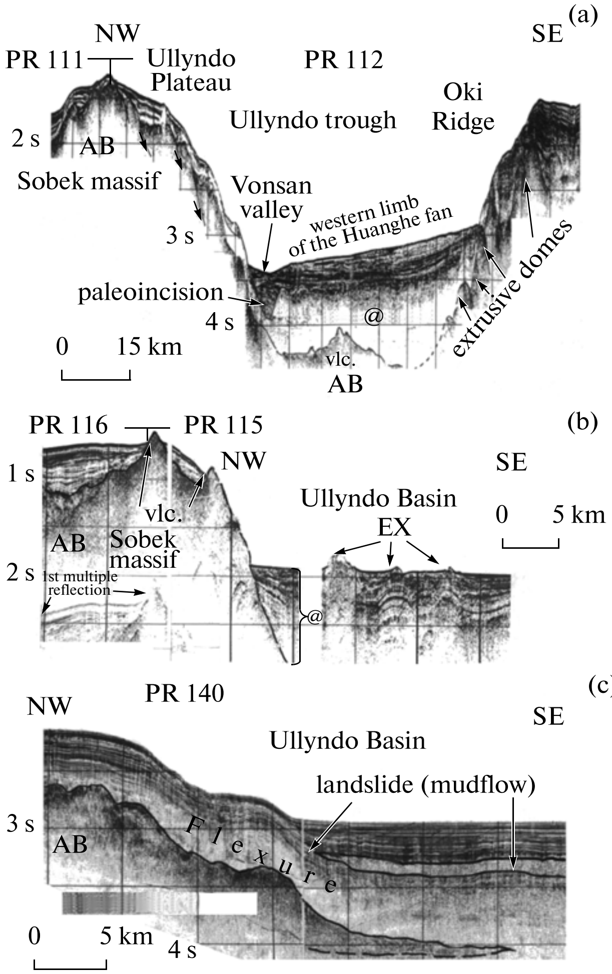

Fig. 7. (a–c) continuous seismic profiling records (Institute of Marine Geology and Geophysics, Far East Branch, Russian Academy of Sciences) across the western slope of the Ullyndo Basin and trough [18].

The vertical scale is in two time travel seconds; the vertical lines designate the half-hour marks here and in Fig. 8b; (B) the acoustic basement here and in Fig. 8b; (ED) extrusive domes; (vlc) volcanoes. For the position of the profiles, see Fig. 6b.

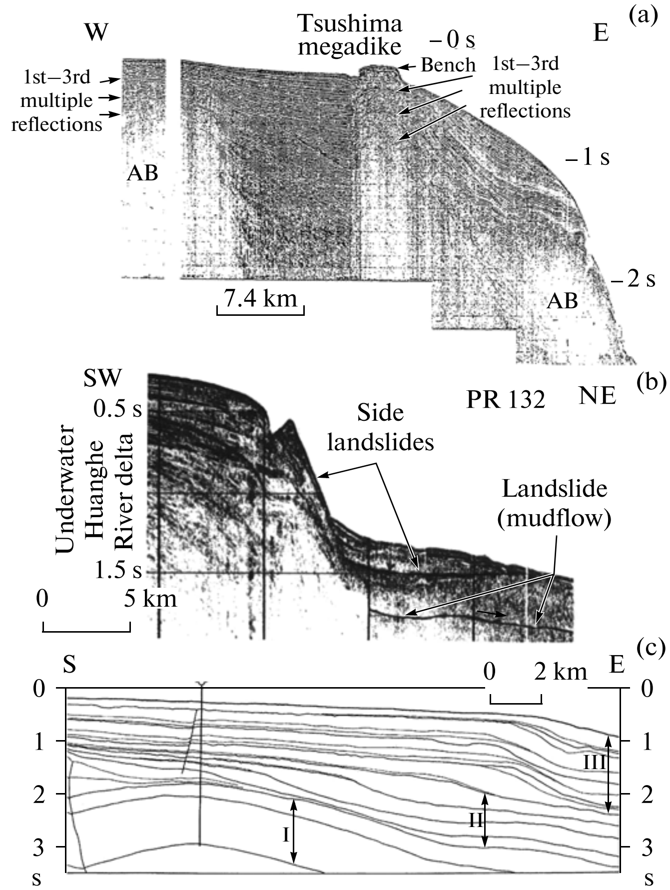

Fig. 8. (a) continuous seismic profiling record (Profile 17 across the Tsushima dike [20, 43]); (b) continuous seismic profiling record (Profile 132 across the southern landslide cirque ("bay") of the Ullyndo Basin); (c) deep CMP section with cross-bedded seismofacies of the underwater Huanghe River delta recovered by the Dolgoran-1 Borehole: (I–III) the sedimentary units dated at 16–12, 12.0–6.5, and 6.5–0 Ma, respectively [18, 37]. For the position of the profiles, see Fig. 6 B.

on nine tsunamis without preceding strong earthquakes. They are classified as tsunamis probably induced by meteorological factors, although some of them may be related to underwater landslides.

CONCLUSIONS

The first relatively complete catalog of earthquakes ($M \geq 3.0$; $h \leq 60$ km) that occurred in the entire Sea of Okhotsk for the period of 1975–2005 has been compiled. The catalog made it possible to obtain more complete distribution patterns of the seismicity in this region and correlate them with the crustal tectonics.

The region under consideration is characterized by the following specific seismicity features. In most areas of the sea, its crust is aseismic. The exception is represented by the borderlands of the Japan–Sakhalin arc and the Sino-Korean Peninsula underwater margins with a zone of shallow-focus, mostly crustal seismicity up to 100–200 km wide. Behind the island arc, this seismicity band narrows from its flanks toward the central part and deepens from 30–40 to 60 km. In the seismic sections, it exhibits a near-vertical dip probably marking the root zone of the frontal deep-seated thrust and the regional bend of the crust and the subcrustal mantle layers at the transition from their subhorizontal position beneath the Sea of Japan to the inclined one under the borderland.

It is assumed that the seismicity through the entire Japan–Sakhalin arc (approximately 2000 km) is controlled by the tectonics: (1) the earth's crust sliding behind the frontal deep-seated thrust (the Oyashio overthrust in Japan and the Central Sakhaklin updip–thrust on Sakhalin); (2) the formation of the regional reversed faults or, more exactly, their system (megaduplex) and the divergent structure of the island arc.

The crustal seismicity under the southeastern margin of the Korean Peninsula (the Sino-Korean Shield) is likely related to the Tsushima and Ullyndo faults. Special attention should be paid to monitoring of the crustal seismicity and the block presumably tsunamigenic landslides in the southern and eastern cirques of the Ullyndo Basin incised into the marginal part of the Neogene–Quaternary underwater Huanghe River delta.

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